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A Novel Aircraft Instrument Display to Minimize the Risks of Spatial Disorientation

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By

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June 1995

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A novel instrument display designed to reduce cognitive workload was tested against a standard instrument panel using a helicopter mockup linked to a computer flight simulator. Both pilots and nonpilots were used as subjects and tests involved recovery from unusual aircraft attitudes as well as flight maneuvering instruments. The novel display incorporates heading, speed, roll, and pitch into a single tracking task. Users set the desired heading and the desired speed (and the desired altitude and glide path). The display then guides control movements to achieve and maintain the desired parameters. Results from the unusual attitudes experiment showed significant benefits from the novel display, evident in improved performance on a secondary task (noise identification) and reduced control input errors. Results from the flying portion of the study showed significantly improved performance at the secondary task together with improved speed control when using the new display, although heading control was reduced. Further modifications to the new display have been introduced since these initial experiments, and further testing should be carried out using dynamic
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19. Abstract (Continued)

displays during unusual attitudes and continual data collection during flight. The display should be developed further to make it possible to utilize it in a HUD or other NVD and to give it the capability to display hover information.

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Introduction

It has long been known that humans cannot maintain straight and level flight in the absence of visual cues (Anderson, 1919). It also has long been known that the human organs of balance not only fail to give sufficient cues for accurate perception of position or motion during aviation, but may give erroneous cues (for overviews see Guedry, 1974 and Benson, 1988). The common result of insufficient or misperceived cues, whatever their origin, is a state of spatial disorientation (SD), commonly defined as the predicament "...when the aviator fails to sense correctly the position, motion, or attitude of his aircraft or of himself within the fixed coordinate system provided by the surface of the earth and the gravitational vertical" (Benson, 1988).

The significance of SD is demonstrated by 32 percent of U.S. Army class A-C rotary-wing accidents involved SD as the major contributing factor (Durnford et al., 1995). Many of these accidents would occur whatever type of instrument display was in use, since the aircrew are simply not looking at the instruments. However, there are a number of accidents which involve the classically disorientating conditions of inadvertent entry to instrument meteorological conditions (IMC), whiteout or brownout, and which might be amenable to improved instrument displays. These accidents represent some 25 percent of U.S. Army rotary-wing SD accidents, although they constitute a considerably higher proportion in other groups such as general aviation rotary-wing accidents (Adams, 1989). In addition to these accidents, there are those in which an easily understood instrument display may prevent the initial circumstances leading to disaster by either providing an easy source of information against which aircrew might check their progress or by providing a simple symbology which could be superimposed upon external views (as in a head-up display [HUD]).

Present day helicopter instrument panels are derived from fixed-wing aircraft and are designed to provide information about forward flight. They do not give reliable information about hovering. Even in forward flight, the panels are not easy to interpret because of the following five standard aircraft parameters that need to be monitored and integrated: aircraft

attitude, airspeed, altitude, rate-of-climb or rate-of-descent, and aircraft heading. Some aircrew have difficulty doing this even during routine instrument flight. The panic associated with SD makes reading and understanding five separate instruments even more difficult (Benson, 1988).

Although it is relatively easy to identify the possible benefits of an improved instrument display in which all five parameters were integrated, it is less easy to identify a suitable design. This is particularly true if one accepts the usual aim of giving the pilot a constant mental image of aircraft orientation. Under this traditional system, the pilot has to continually monitor the aircraft's orientation and react with the appropriate control inputs. Therefore, the pilot needs to gather information on all aspects of the aircraft's position and motion.

To reduce this workload means moving away from this traditional aim. A new concept was developed in which the pilot would be able to specify particular parameters (such as speed or heading) and then match his control inputs to a simple, integrated display which would ensure that those parameters were maintained (or, if necessary, recovered). In effect, the concept was to replace a high level cognitive task with a comparatively low level tracking task. In the new display, the pilot can check any parameter at any time (for example, altitude or airspeed), but is freed from the requirement to <u>continually</u> sample these parameters to maintain stable flight. Situational awareness is in no way reduced; the pilot is aware entirely of the aircraft's orientation, but is spared the burden of monitoring it.

This paper describes the initial results of tests on this display concept.

Design aims of the novel display

- To produce a simple display which would provide an easy source of information for reorientation during episodes of SD, while also providing an adequate source of information for standard instrument flight.

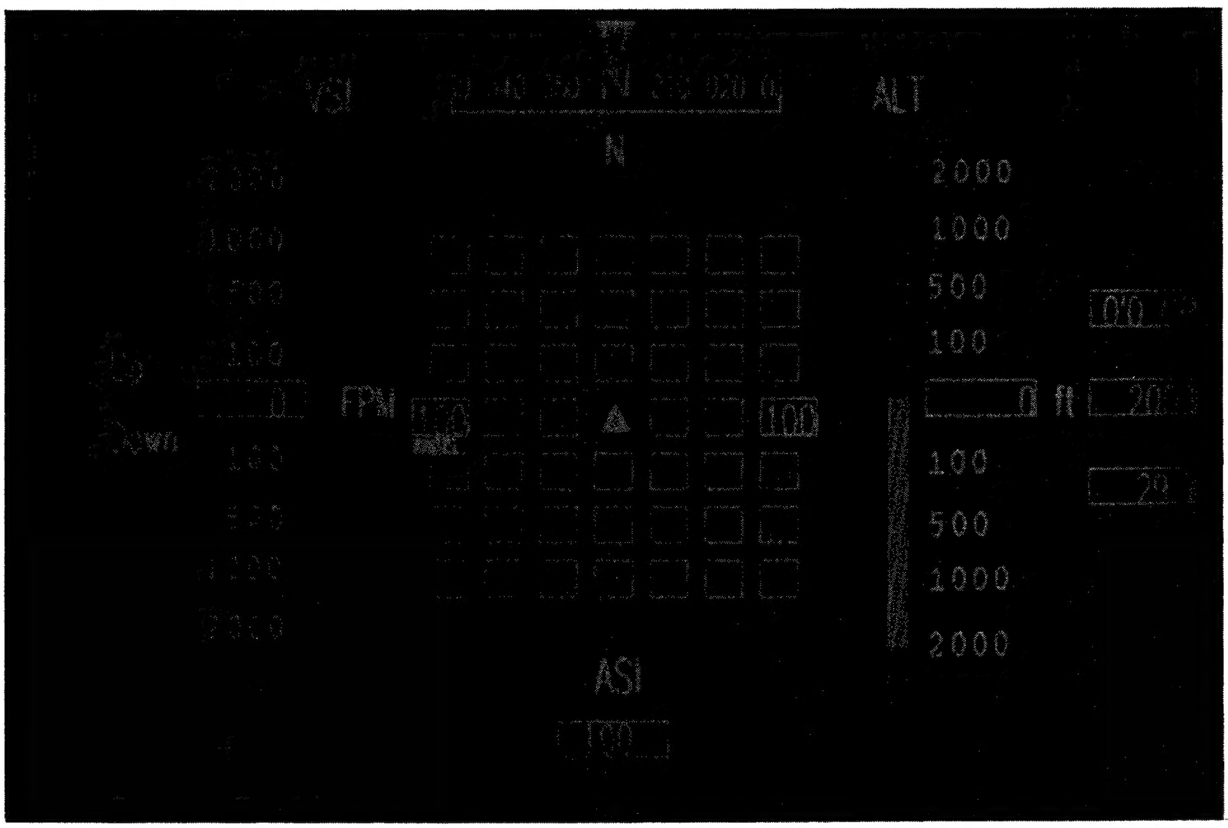

Figure 1. The novel display.

- To produce a prototype display which could be developed further as a head-up or injected symbology display.

- To produce a framework which could be used later to give hover information (either as an integral part of the complete display or as a switch over function).

Details of the novel display

Figure 1 shows the novel display used in this experiment. The display has evolved further since it was tested (see conclusions).

The central field of the display consists of a series of squares (themselves arranged in a square) and a small triangle. The triangle moves across the squares as a function of aircraft speed and heading. (The x-axis represents heading and the y-axis speed.) Movement of the triangle along these axes is a derivative of the orientation functions of pitch and roll since speed depends on pitch inputs and heading on roll inputs.

Aircraft speed and heading

Fore and aft cyclic movements are used to maintain the desired aircraft speed by steering the triangle to the midline on the x-axis. Lateral cyclic movements do the same for the heading using the y-axis. Thus, if the triangle is kept in the central box, the aircraft will remain steady on both the desired speed and heading.

The compass tape across the top gives the actual heading and the box below the desired heading.

The air speed indicator (ASI) below the central squares gives a digital readout of aircraft speed. The numbers inside the lateral squares give the relative speed corresponding to that position on the y-axis. Similarly, the numbers above and below the squares give the relative number of degrees away from the desired heading that is appropriate to that position on the x-axis.

Because speed and heading are in themselves no absolute indications of pitch and roll (and aerodynamics makes it essential that these are controlled), there is a vector that has its origin in the center of the triangle. As the aircraft pitches forward, the line extends forwards. As the aircraft pitches back, the line extends backwards. This vector also is linked to roll and therefore has a 360° arc of freedom. The size, as well as the direction, of the vector is resolved from both pitch and roll, thus making it possible for pilots to control these parameters. Furthermore, because speed and heading depend on pitch and roll, this vector points the way that the triangle shortly will begin to move. Pilots can anticipate speed and heading changes and use the vector to steer the triangle.

Since this experiment, the vector has been replaced with a much simpler system which drives the triangle's position through combinations of roll angle with heading and pitch angle with speed. Positioning the triangle within the central box now means that the aircraft will regain and then retain the desired speed and heading (see recommendations).

Aircraft altitude

Altitude is color coded. The triangle maintains a green color if the altitude is at the desired level (or up to 100 feet above), a red color if it is lower, and a blue color if it is higher. The altimeter to the right of the squares reinforces height information by showing the specific altitude (in digital readout form) as well as the difference between the actual altitude and the desired altitude (in color coded tape form). Boxes display the current settings for the desired altitude and pressure setting. The vertical speed indicator (VSI) on the left of the squares acts in much the same way as the color coded tape display of the altimeter. It is placed on the left because it is the instrument that responds most quickly to control inputs from the collective lever in the pilot's left hand. (Research has shown that information displays should, where possible, be on the same side as the relevant control, Hartzell et al., 1983).

Methods

The novel display was tested against a standard instrument display using a helicopter cockpit mockup with full size controls linked to a simulator program run on a Silicon Graphics Iris Indigo XZ machine*. A photograph of the cockpit mockup is at Figure 2. The standard display used is shown in Figure 3. For each subject, there were two series of experiments. One involved recovery from unusual attitudes and the other involved flying. Subject performance at these tasks was measured. In addition, the use of attentional resources was estimated by measuring performance at a secondary task involving the identification of high or low tones.

Unexpected software and hardware limitations meant that it was not possible to begin an episode of simulated flight in an unusual attitude. (Altitude, speed, and rate-of-climb or rate-of-descent could be varied at the start of each episode, but neither roll nor pitch could be.) This meant that only static displays were used in the experiments involving recovery from unusual attitudes. Similar limitations prevented us recording moment-to-moment flight path data, and so measurements in the flying experiments were restricted to how close subjects came to achieving the desired flight path by the end of each session.

Recovery from unusual attitudes

Subjects were exposed to a series of eight static panels representing unusual aircraft attitudes. They then were exposed to a second series using the other instrument panel. Half the subjects used the standard display first, while the other half used the new display. Unknown to the subjects, the second set of unusual attitudes was the same as the first, but in reversed order so as to counterbalance any learning effects when data were pooled across subjects. These unusual attitudes involved pitch ranges from -30° to +30°, roll ranges from 60° left to 60° right, airspeeds from 35 kts to 135 kts, and vertical speed rates from

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*See manufacturers' list.

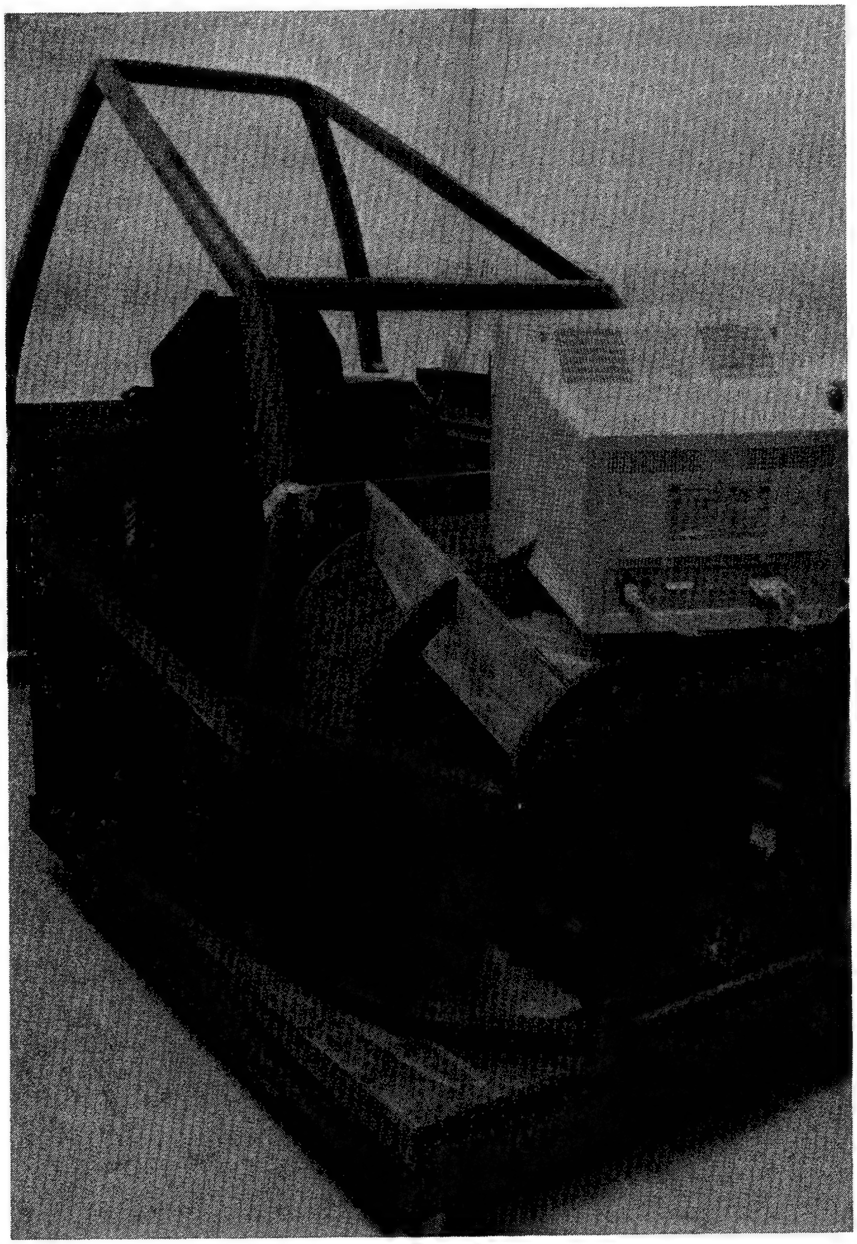

Figure 2. The cockpit mockup.

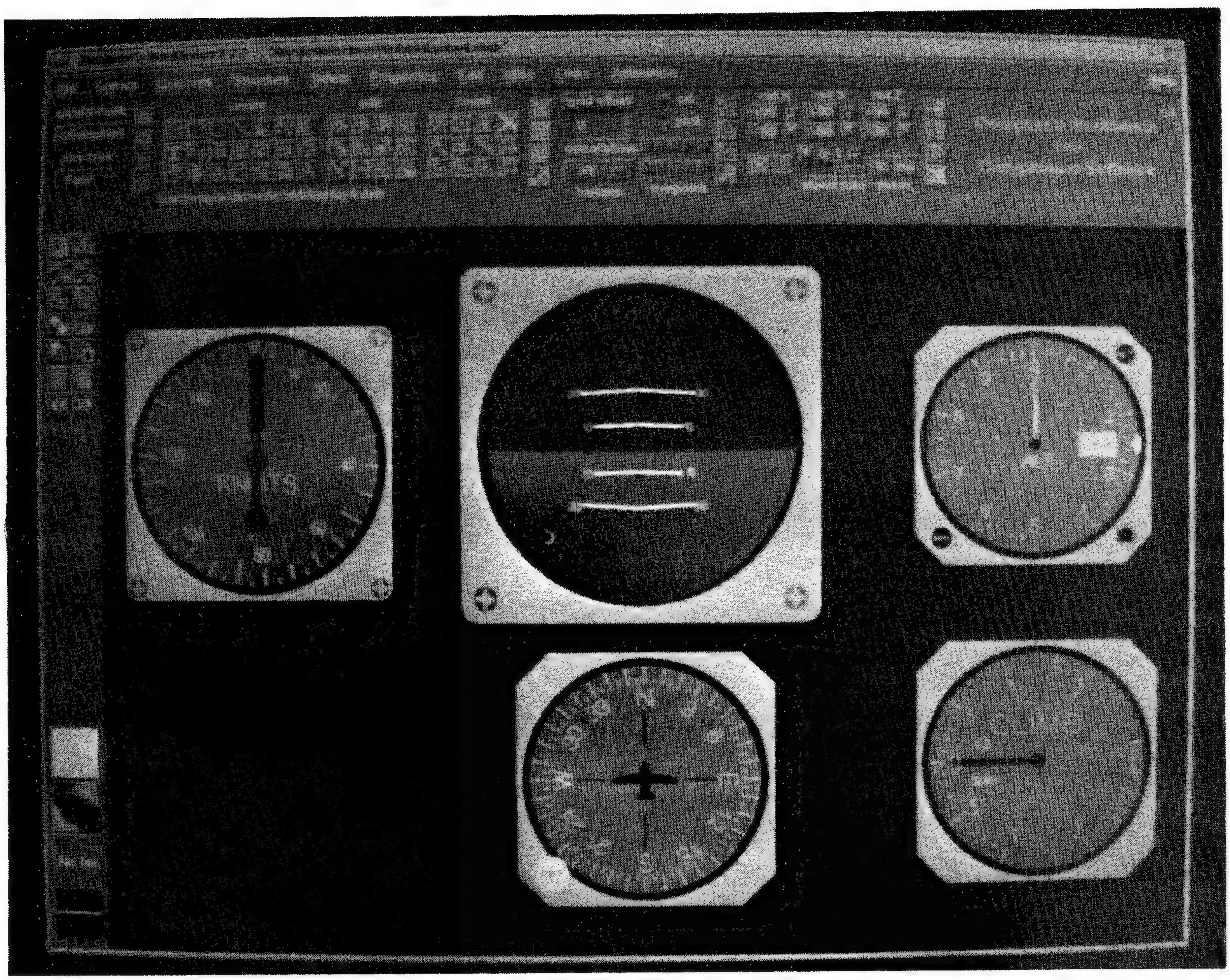

Figure 3. The standard display.

2000 fpm climb to 2000 fpm descent. Figures 4 and 5 show an identical unusual attitude as it would be presented on the standard and the novel displays.

Subjects had 15 seconds to respond to the display by making control movements in the appropriate direction for bringing the helicopter back to straight-and-level flight (phase 1). This task required the subject to respond to pitch, roll, and rate-of-climb or rate-of-descent. An observer monitored their control inputs in terms of cyclic fore/aft, cyclic left/right, and collective up/down. The observer also monitored any indecision, as evidenced by corrections to the control inputs.

During this 15-second period, subjects also were exposed to the secondary task described later.

After the 15 seconds, the display was removed from sight and subjects were asked what further control inputs would be necessary to return the aircraft to a heading of north, an altitude of 2000 feet, and a speed of 100 kts (assuming they had achieved straight-and-level flight at the heading, speed, and altitude originally displayed). This task was phase 2 and required subjects to remember information on the display concerning heading, altitude, and speed.

The flying task

The flying task consisted of four flights with each display. Each flight lasted 1 minute, during which period subjects had to achieve the following parameters:

- 100 kts (from a starting speed of either 80 kts or 120 kts)

- 2000 ft (from a starting point of 1500 ft or 2500 ft)

- A heading of west or east (from a starting point of north)

Subjects also were exposed to the secondary task for the full period.

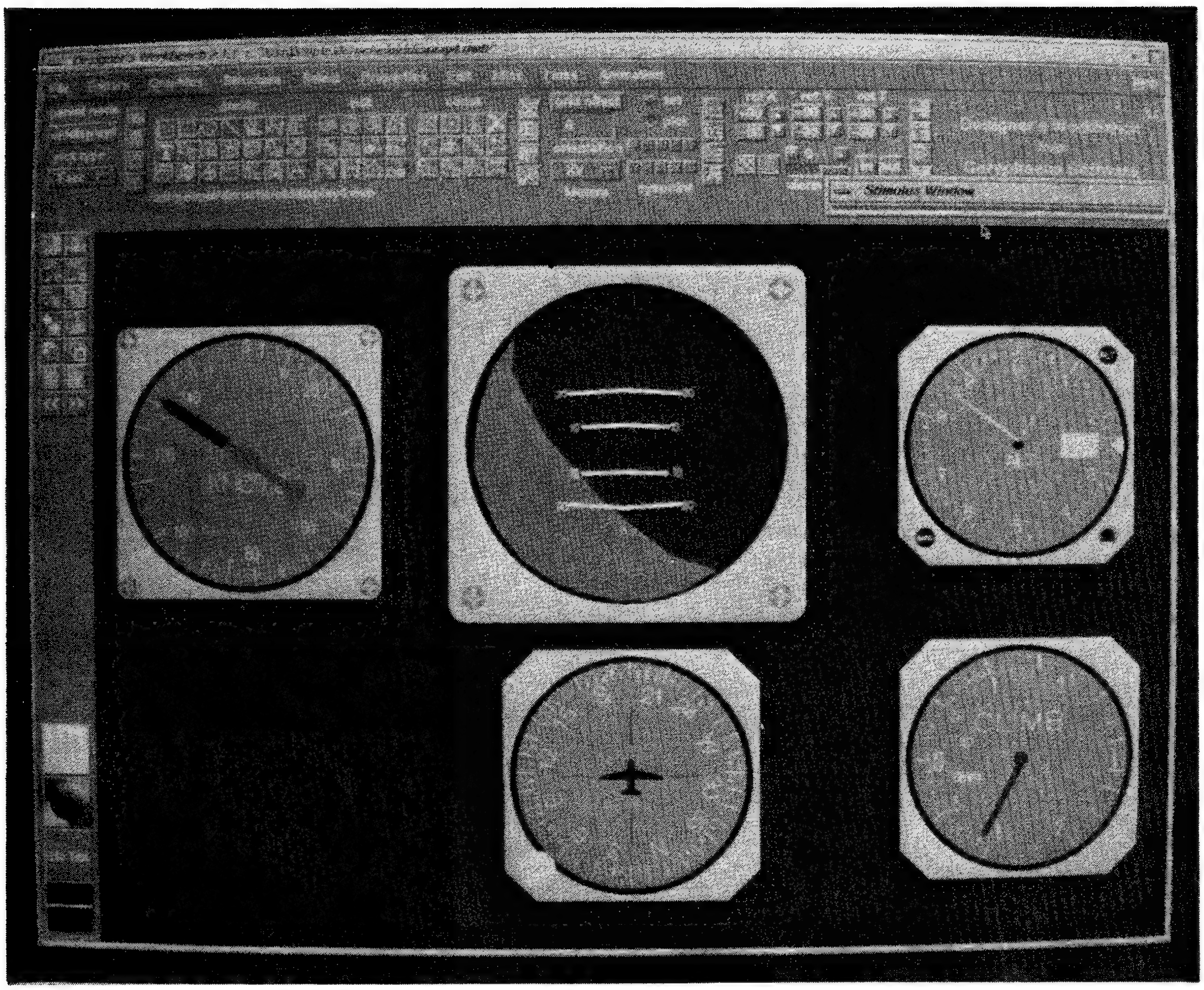

Figure 4. An unusual attitude as displayed on the standard panel.

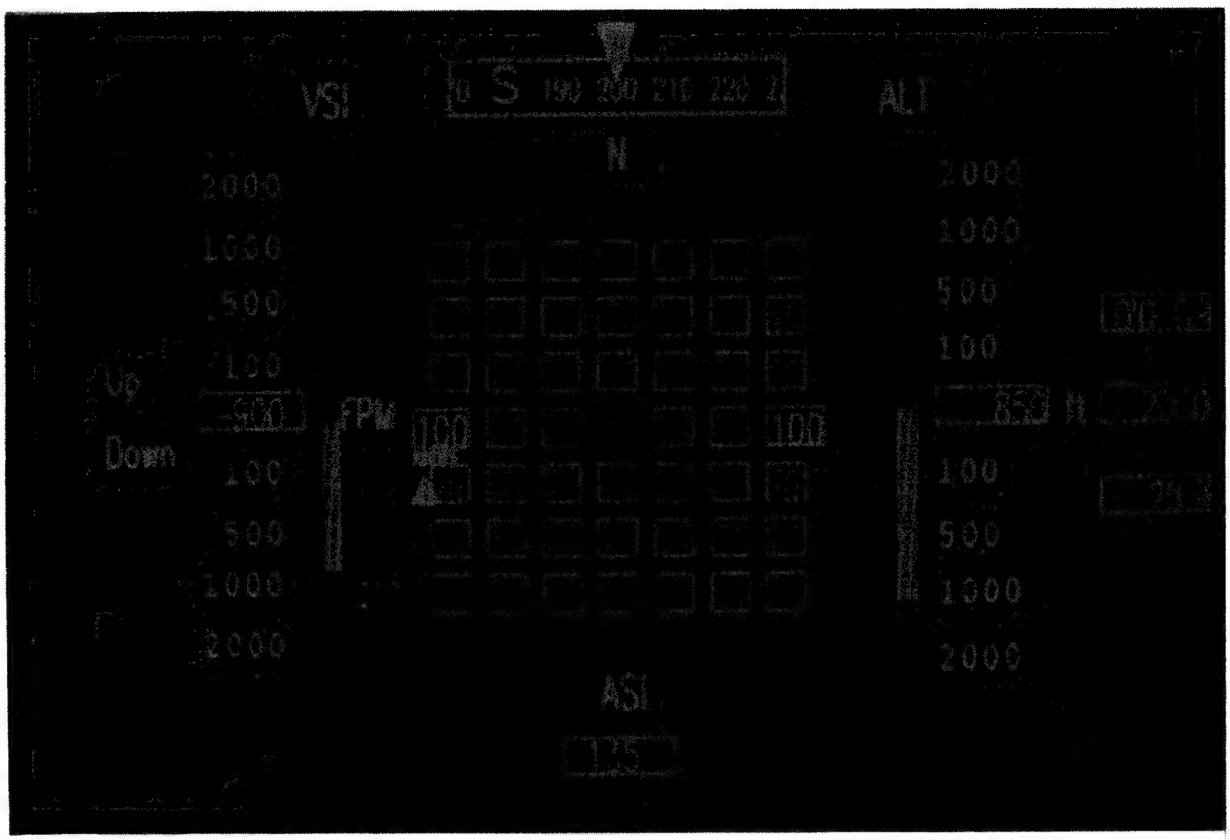

Figure 5. An unusual attitude as displayed on the new display.

As for the unusual attitude part of the experiment, the order in which the displays were used were balanced across subjects. Each subject was exposed to the same starting parameters twice (once with each display).

Because it proved difficult to record moment-to-moment flight data, these episodes were scored on how close subjects came to achieving the desired parameters at the end of the minute period and on their scores for the secondary task. In addition, final roll angle, pitch angle, and rate-of-climb or descent were measured.

The secondary task

The secondary task was incorporated into the experiments to give a measure of the spare attentional resources available to subjects while they were performing the primary tasks. An American Computer Zero Input Tracking Analyzer* (ZITA) machine was used for this task. This machine has been extensively described in previous studies (see, for example, Simmons et al., 1989).

The subject was required to identify a high or a low tone by pressing an appropriate button on the cyclic handgrip before the next tone was played. Tones were played at a rate of 1 per second. The total number of responses, together with the numbers of correct and incorrect responses, were used as dependent measures.

Subject questionnaires

Subjects were asked to rate the ease of use of the new display against the standard display by selecting one of the following options:

- The new display was much more difficult to use than the standard display.

- The new display was more difficult to use than the standard display.

- There was no difference in the ease of use of the two displays.

- The new display was easier to use than the standard display.

- The new display was much easier to use than the standard display.

Subjects did this immediately after the unusual attitudes part of the study and again immediately after the flying part of the study. In the latter part, pilot subjects also were asked how they would rate the new display if they had flown as many hours using the new display as they had previously flown using the standard form of panel.

Subjects

Five aircrew in current flying practice and five nonaircrew subjects were used.

Each subject was in normal health and free from medication. All were able to easily hear and identify the low and high tones of the secondary task.

Subjects were given both a written and an oral brief. All signed volunteer consent forms.

Training and experimental profile

Subjects were given a minimum of 1 hour of training on the helicopter simulator program, the two display formats, and the secondary task. Training began with a general explanation of the two displays. Subjects then were taken through the specific information provided by the two displays with regard to airspeed, heading, altitude and rate-of-climb (or descent). Once they confirmed they understood the information given by the displays, they were shown how changes in pitch and roll initiated by cyclic changes affected the attitude indicator on the standard panel and the yellow vector line on the novel display. Then, they also

were shown how changes in pitch and roll had secondary effects on speed, heading and rate of climb (or descent). During this phase they were encouraged to play with the cyclic controls until they felt familiar with how the displays responded. Next, they were shown how movements of the collective affected the displays in terms of rate of climb (or descent) and altitude. Again they were encouraged to play with the collective. Once they felt comfortable with the effects of moving the collective, they were asked to put cyclic and collective movements together to see the influence on the displays. Periods of rest were offered as and when needed.

Subjects only went forward to the next phase once they had confirmed they felt generally comfortable flying the two displays and, that they understood the information provided by the displays and how control inputs affected them. In this phase, they were given further training on how the displays provided information about unusually extreme aircraft attitudes, beginning with whichever display they would be using second in the experiment. The static displays used in training were similar to those used in the experiments, but care was taken to ensure that none of the experimental unusual attitudes were used for training. Subjects were trained until they demonstrated on at least four consecutive occasions that they could interpret correctly unusual attitudes involving deviations in airspeed, rates-of-climb (or descent), altitude and heading, and that they could integrate these with the information from the attitude indicator (or yellow vector) to derive the required control inputs to recover the aircraft to safe and level flight and then to the original flight path. Once they had confirmed they felt comfortable with the task using this first display, they received training on the other. After demonstrating competence with the second display, they entered the study. Following the first set of unusual attitudes, they received refresher training on the other display until they again confirmed that they felt comfortable enough to be exposed to the second set of unusual attitudes.

Prior to the flying part of the study, they were given further training and practice on maneuvering the simulator using the display most recently used for the unusual attitudes. No accuracy standards were required of subjects, other than the

ability to fly the aircraft for a period of 2 minutes or more without crashing since it was expected that proficiency would be highly variable. When they confirmed that they felt comfortable with this, they performed the four flying tasks with this display. They then received further training on maneuvering using the other display, and when comfortable with this, they performed the same four flying tasks again.

All subjects were introduced to the secondary task during the period they first started putting cyclic and collective control movements together to fly the simulator. Subsequently, the secondary task was introduced into the training for each experimental section as subjects began to demonstrate competence.

Subjects were told they would be scored on all parts of the experiment and should spread their attention across as many aspects as possible (with the single exception that they could, if necessary, concentrate on avoiding a crash during the flying phase).

Results

Objective results

The results for each subject were collapsed to give a mean for each dependant variable (except in the case of control errors, when the errors were summed). They then were analyzed in two groups, those resulting from the unusual attitude portion of the study and those from the flying part of the study.

Unusual attitudes

Shapiro-Wilks' tests showed that the means on the secondary (ZITA) task were normally distributed (e.g., $p>0.0897$ for the correct ZITA responses using the standard display, $p>0.820$ for correct responses using the new display). Therefore, these were analyzed using ANOVA with one grouping variable (pilots and non-pilots) and one repeated measure (standard display or new display).

The pattern of control errors, however, never came close to a normal distribution, even after various transformations (e.g., Shapiro-Wilks' p<0.0.0004 for errors on phase 2 after log transformation). Therefore, these results were analyzed using Wilcoxon tests.

Table 1 gives the mean ZITA responses grouped by display and pilot status. Univariate ANOVA showed a strong display effect on both the total number of responses and the number of correct responses (p=0.003 and p=0.004 respectively). There was no significant display effect on the number of incorrect responses and no pilot effect on any of the variables.

Table 1.
Secondary task (zita) scores while recovering from unusual attitudes.

	Mean total ZITA score		Mean correct ZITA score	
	Standard display	New display	Standard display	New display
Pilots	9.65	11.88	6.75	9.38
Nonpilots	10.74	11.90	8.59	9.34
All SS	10.19	11.89	7.67	9.36

The scores given are mean total score and mean correct score broken down by pilot and display groups.

During the experiment, control error data were collected according to the control involved (cyclic or collective) and the direction of input, as well as by the task (recovery to straight and level flight, or recovery to the original flight path). The number of corrections to control inputs during the first phase also was recorded. In order to limit the number of statistical tests performed, these errors were summed across the two different groups (pilot and nonpilot), providing a set of paired data for a single Wilcoxon* test (standard display versus new display). These total numbers of control errors are given in Table 2 below, together with the totals for the different phases. The Wilcoxon test on the grand total showed a significant reduction in control errors when the new display was used (p=0.0077).

Table 2.
Numbers of control errors made during the recovery from unusual attitudes summed across subjects.

	Total errors		Errors in 1st phase		Corrected inputs		Errors in 2nd phase	
	'old' panel	'new' panel	'old' panel	'new' panel	'old' panel	'new' panel	'old' panel	'new' panel
Pilots	67	38	28	22	14	5	25	11
Non-pilots	90	27	40	13	18	8	32	6
All SS	157	65	68	35	32	15	57	17

Further investigation (by grouping the data according to pilot/nonpilot status and phase of recovery) revealed that these significant differences lay primarily in the nonpilot group. There were no significant differences in the pilot data when taken alone, whereas the nonpilot data showed display differences in both the number of corrected control inputs and the number of errors made on phase 2 (at the $p=0.043$ level). Adding the pilot data strengthened the significance level in both these groups ($p=0.019$ for the former and $p=0.017$ for the latter), indicating that the pilot data was in a similar direction even if it did not reach significance.

Flying data

Secondary task scores during the flying portions of the experiment, like those during the unusual attitudes, showed normal distributions (e.g., Shapiro-Wilks' $p>0.6$ for correct ZITA scores when using the standard display, and $p>0.94$ when using the new display). These scores were analyzed using ANOVA.

Mean errors in accuracy at achieving the desired final flight parameters were not, on the whole, normally distributed (e.g., the Shapiro-Wilks' p value for the final roll angle when using the standard display was <0.0001). Log transformation was able to bring them into an acceptably normal range (e.g., the new Shapiro-Wilks' p value for the log of the final roll angle when

using the standard display was 0.41). The sole exception was for the final pitch angle when using the standard display, whose Shapiro-Wilks' recovered only to p=0.03 from an initial value of p<0.0000. ANOVA was performed on the log transformations.

Table 3 gives the mean secondary task (ZITA) scores for the flying portion of the study. ANOVA revealed a significant display effect on the number of incorrect responses (p=0.023) but no pilot effect. There were no significant effects on the number of correct responses or on the total number of responses, although the display effect on the number of correct responses nearly reached significance (p=0.08).

Table 3.
Mean scores on the secondary task (ZITA) during the flying portion of the study broken down by display and pilot status.

	Incorrect ZITA responses		Correct ZITA responses	
	Standard display	New display	Standard display	New display
Pilots	12.95	10.35	31.33	35.15
Nonpilots	11.10	8.80	30.15	32.65
All SS	12.03	9.58	30.74	33.90

Table 4 shows the final accuracy in achieving the desired flight parameters broken down by display and pilot status. ANOVA on the log of these values revealed display effects in airspeed and heading (the new display was associated with more accurate airspeed but less accurate heading, p=0.038 and p=0.043, respectively). Pilot effects were shown on heading and altitude (pilots were more accurate than nonpilots, p=0.035 and p=0.0074, respectively). No effects could be shown on rate-of-climb or descent, pitch angle or roll angle.

Table 4.
Final accuracy in achieving desired flight parameters broken down by display and pilot status.

	Airspeed (kts)			
	Standard display		New display	
	Range	Mean	Range	Mean
Pilots	7-38	16.0	4-28	10.75
Nonpilots	18-45	26.3	1-27	12.2
All SS	7-45	21.1	1-28	11.5
	Heading (degrees)			
Pilots	2-9	6.0	4-42	14.8
Nonpilots	6-39	19.0	8-83	37.0
All SS	2-39	12.5	4-83	26.1
	Altitude (feet)			
Pilots	129-337	229	270-415	335
Nonpilots	224-934	602	361-1060	667
All SS	129-934	415	270-1060	501
	Rate of climb or descent (feet per minute)			
Pilots	4-20	12.4	4-34	15.8
Nonpilots	10-59	26.6	7-28	15.9
All SS	4-59	19.5	4-34	15.9
	Pitch angle from zero (degrees)			
Pilots	2-6	3.8	3-9	5.5
Nonpilots	3-35	10.9	2-7	4.5
All SS	2-35	7.3	2-9	5.0
	Roll angle from zero (degrees)			
Pilots	1-6	3.9	4-10	6.6
Nonpilots	1-31	9.6	2-6	4.0
All SS	1-31	6.8	2-10	5.3

Subjective questionnaires

Pilots

Four out of the five pilots rated the new display as much easier to use for recovery from unusual attitudes; the other marked it as easier.

Given their present level of training and experience, three pilots considered the new display less easy to fly with than the standard panel; two considered it to be no different.

When considering how the new panel display would compare against the standard panel, given equal flying experience with both displays, one pilot considered the new panel would be much easier to use than the standard panel. Two considered it would be easier and one considered there would be no difference. One failed to record an opinion.

Nonpilots

In an identical result to the pilot group, four out of the five nonpilots marked the new display as much easier to use for recovery from unusual attitudes; the other marked it as easier.

Given their present level of training and inexperience, two nonpilots considered the new display much easier to fly with than the standard panel, two considered it to be easier, and one considered it to be no different.

Discussion

Recovery from unusual attitudes

It is recognized that a static display of an unusual attitude is unrealistic in that aircrew receive a great deal of information from the manner in which their instruments change. Nonetheless, it is considered that the tests carried out here gave a fair indication of the ease with which subjects were able to extract information concerning flight parameters from each display. Further testing with dynamic displays is, of course,

essential and must be a future aim. (Such testing was the original aim of this study.)

The pattern of benefits associated with the new display was similar for both pilots and nonpilots. Although the ANOVA showed no pilot effects on ZITA scores, the benefits in the pilot group tended to show most in better ZITA scores, while the benefits in the nonpilots tended to show most in reduced control input error rates. Nonpilots were included in the study because of the potential bias in aircrew associated with their many hours of instrument flying using a standard panel. It was postulated that this bias might negate the possible workload benefits associated with the new display. Therefore, it is interesting and reassuring that the reduced workload (as implied by improvements in the secondary task scores) was observed mostly in the pilots. The findings in nonpilots suggest that the unusual attitude task was of sufficient difficulty for them to allocate a relatively fixed level of attentional resources to the task (whatever display was used). Also, this is suggested because, for them, the advantages of the new display showed up in a much reduced error rate.

These patterns lend objective evidence to support the questionnaire results, which showed that both pilots and non-pilots found the new display considerably easier to interpret than the standard panel.

During the experiments, one limitation with the new display was noted, namely that the vector could confuse rather than simplify. Subjects (both pilots and nonpilots) occasionally applied control inputs in the opposite direction to the vector line. The original intention of the display design was to create a simple put-the-triangle-in-the-box display without any need for vectors. This has been achieved subsequent to the experiment by linking the triangle's movement to pitch and roll and then adapting it to speed and heading. The triangle moves 1 cm for every 10^0 of roll (on the x-axis) or 10^0 of pitch (on the y-axis). This movement is not capped. The triangle also moves 1 cm for every 20^0 of deviation from the desired heading (x-axis) and 20 kts of deviation from the desired airspeed (y-axis). These latter movements are capped to a maximum of 30^0 heading difference and 25 kts airspeed difference. (These figures are

arbitrary experimental values and could be varied as needed). The result is that if the pilot returns the triangle to central square and keeps it there, the aircraft will regain and then retain its desired heading and speed using no more than a 15^0 angle of bank and 12.5^0 angle of pitch. The new version of the display should allow an even greater reduction in workload when dealing with unusual attitudes and should be as easy (or easier) to fly. Only further experimentation can confirm this.

Flying

The principal concept behind the new display was to provide a "get-me-out-of-trouble" device. Nonetheless, it was important to find out whether the display could be used for normal instrument flight, and if so, what advantages and disadvantages might apply.

Overall, there appeared to be little difference in flying performance using the two displays. There were two significant results implying benefits from using the new display, namely improved speed control and fewer incorrect ZITA responses. There was one disadvantage, namely reduced heading control. With regard to heading control, two factors should be noted:

- The x-axis across which the triangle moved (from one side of the set of squares to the other) represented the whole 360° compass arc. The scale therefore was small and accuracy was difficult to obtain. The modifications to the display since the experiment have rectified this.

- Should the display ever be introduced into an aircraft, the intention would be that the pilot has the option of dialing up any required changes in heading and then flying the triangle back into the central box to attain that heading. In this experiment, software limitations prevented this strategy and subjects had to fly the triangle out of the box to a point that equated to a heading 90° from the original. This may have influenced the results.

Therefore, it seems likely that the new display, when reconfigured, will be no worse as a flying aid than the standard

panel and may well be better. This is supported by the subjective opinions of both the pilot and nonpilot groups. The objective results of this experiment are limited, however, by being based solely on the final parameters achieved. They give no information on aircraft control during each flight, and further experiments involving continual data collection are necessary. (No obvious differences in aircraft control were noted by the experimenters, and the only aircraft crash occurred when a nonpilot subject was using the standard panel.)

Laboratory results versus real life requirements

This experiment was carried out in a laboratory setting using a static helicopter mockup. Real flying takes place in very different conditions, and it is dangerous to assume that a source of flight information that appears better in a laboratory will necessarily prove better in the air. The next step in the development of this display should utilize a more realistic environment such as a full motion simulator (or a real aircraft).

It should be noted, in particular, that this new display intentionally gives no indication of the position of the horizon. Aircrew flying visually do so by orientating themselves to the horizon. If they fly into marginal weather or into mountainous terrain (where horizon lines may be difficult to determine), they may check their instruments to confirm the attitude of their aircraft. The new display will give no immediate confirmation of the position of the horizon, although it could easily be adapted to do so.

Adapting the display for use in a HUD or NVD

No attempt was made in this experiment to superimpose the display on a scene depicting the outside world. However, the display was designed with that use in mind, and further development along this path now might be warranted. The central squares, and all the other elements, could be replaced or adapted in such a way that they would be less obscuring.

Adapting the display to provide hover information

Similarly, no attempt was made to provide hover information on the display. However, the design easily could be adapted for this purpose and further development along these lines might also be beneficial. It is envisaged that the display would be re-configured to give hover information by dialing the desired airspeed to zero. Airspeed figures then would become groundspeed figures and movement of the triangle from the central box would represent roll and pitch angles modified by the distance moved from the hover spot. The same sort of algorithms could be used as for the flight mode. This particular development would require accurate drift information from GPS or other systems. Hover mode would have to be differentiated clearly and visibly from flight mode to avoid aircrew confusion.

Conclusions

The results of this experiment provide strong evidence that the concepts behind the new display are workable, and that the new display would make recovery from unusual attitudes (and quite probably instrument flying) easier than when using the standard panel.

However, limitations in the experimental design caused by software and hardware difficulties mean further testing is desirable. This testing should take place in an environment that is as realistic as possible and should use the postexperimental modifications to the display.

The display should be developed further to make it possible to superimpose it on outside scenes. In addition, it should be developed to be able to provide information on hovering.

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Appendix A.

List of manufacturers

American Computer and Electronics Corporation
Gaithsburg, MD 20879

Coryphaeus Software
985 University Avenue, Suite 31
Los Gatos, CA 95030

Silicon Graphics Computer Systems
2011 North Shoreline Boulevard
Mountain View, CA 94039-1389

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Naval Air Development Center
Technical Information Division
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National Naval Medical Center
Bethesda, MD 20814-5044

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Institute of Environmental Medicine
Natick, MA 01760

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Washington, DC 20307-5001

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Fort Monmouth, NJ 07703-5305

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FAA Technical Center
Atlantic City, NJ 08405

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5109 Leesburg Pike
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Harry Diamond Laboratories
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2800 Powder Mill Road
Adelphi, MD 20783-1197

Headquarters (ATMD)
U.S. Army Training
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Fort Monroe, VA 23651

U.S. Army Materiel Systems
Analysis Agency
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Hygiene Agency
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Fort Rucker, AL 36362

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Air Force Base, OH 45433

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University of Illinois-Willard Airport
Savoy, IL 61874

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Arlington Hall Station
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